

15th Meeting of the Working Group on Rad. Corrections and MC Generators for Low Energies

April 11, 2014 in Mainz, Germany

Editors: S. E. Müller (Dresden) and G. Venanzoni (Frascati)

ABSTRACT

The mini-proceedings of the 15th Meeting of the “Working Group on Rad. Corrections and MC Generators for Low Energies” held in Mainz on April 11, 2014, are presented. These meetings, started in 2006, have as aim to bring together experimentalists and theorists working in the fields of meson transition form factors, hadronic contributions to $(g - 2)_\mu$ and the effective fine structure constant, and development of MonteCarlo generators and Radiative Corrections for precision e^+e^- and τ physics.

The web page of the meeting, which contains all talks, can be found at

<https://agenda.infn.it/conferenceDisplay.py?confId=7800>

Contents

1	Introduction to the 15th Radio Montecarlo Working Group meeting	3
	<i>H. Czyż and G. Venanzoni</i>	
2	Short summaries of the talks	4
2.1	Precision tests of unitarity in leptonic mixing	4
	<i>J. J. van der Bij</i>	
2.2	MC Generators for $e^+e^- \rightarrow$ hadrons at Low Energy	6
	<i>S. Eidelman, G. Fedotov, V. Ivanov, A. Korobov</i>	
2.3	Towards a Precision Measurement of the Muon Pair Asymmetry in e^+e^- Annihilation at Belle and Belle II	8
	<i>T. Ferber</i>	
2.4	Direct production of χ_{c1} — a 1^{++} charmonium at e^+e^- machine	11
	<i>Z. Liu</i>	
2.5	Monte Carlo Generators for the study of the process $e^+e^- \rightarrow 2(\pi^+\pi^-\pi^0)$ with the CMD-3 detector	13
	<i>P. A. Lukin</i>	
2.6	Update on the combined estimate of the KLOE ISR measurements	16
	<i>S. E. Müller</i>	
2.7	Gradient method with re-weighted events and its implementation for TAUOLA to fit the three pion mode	18
	<i>J. Zaremba</i>	
3	List of participants	20

1 Introduction to the 15th Radio Montecarlo Working Group meeting

H. Czyż¹ and G. Venanzoni²

¹ Institute of Physics, University of Silesia, 40007 Katowice, Poland

² Laboratori Nazionali di Frascati dell'INFN, 00044 Frascati, Italy

The importance of continuous and close collaboration between the experimental and theoretical groups is crucial in the quest for precision in hadronic physics. This is the reason why the Working Group on “Radiative Corrections and Monte Carlo Generators for Low Energies” (Radio MonteCarLow) was formed a few years ago bringing together experts (theorists and experimentalists) working in the field of low-energy e^+e^- physics and partly also the τ community. Its main motivation was to understand the status and the precision of the Monte Carlo generators used to analyse the hadronic cross section measurements obtained as well with energy scans as with radiative return, to determine luminosities, and whatever possible to perform tuned comparisons, *i.e.* comparisons of MC generators with a common set of input parameters and experimental cuts. This main effort was summarized in a report published in 2010 [1]. During the years the WG structure has been enriched of more physics items and now it includes seven subgroups: Luminosity, R-measurement, ISR, Hadronic VP incl. $g - 2$ and $\Delta\alpha$, gamma-gamma physics, FSR models, tau.

During the workshop the latest achievements of each subgroups have been presented. A particular emphasis has been put to the recent evaluations of the Leading order and Light-by-Light hadronic contributions to the $g - 2$ of the muon. Finally the status of MC generators for R-measurement with energy scan, ISR, and tau decays has been discussed. All the information on the WG can be found at the web page:

<http://www.lnf.infn.it/wg/sighad/>

References

- [1] S. Actis *et al.* [Working Group on Radiative Corrections and Monte Carlo Generators for Low Energies Collaboration], Eur. Phys. J. C **66** (2010) 585.

2 Short summaries of the talks

2.1 Precision tests of unitarity in leptonic mixing

J. J. van der Bij

Institut für Physik, Albert-Ludwigs Universität Freiburg, Germany

First, the LHC has found no direct evidence for the existence of new physics beyond the standard model, neither in the direct search nor in indirect effects in b-physics. As a consequence one should conclude that major extensions of the standard model, for example supersymmetry, technicolor and the like, are ruled out, or more politely are to be considered to be unlikely on experimental grounds. There is also an argument from mathematical physics, that indicates that in the chiral sector at least the standard model is the only possible low energy theory[1, 2]. Therefore only the so-called minimalistic extensions of the standard model are possible. These are extensions, that do not change the fundamental structure of the standard model in a major way, in particular automatically not having flavor-changing neutral currents. These extensions basically consist of inert scalar multiplets, that is multiplets not coupling to fermions, universal Z' bosons, coupling equally to all generations, and finally sterile neutrinos. Such extensions are helpful in cosmology and can relatively easily explain a number of problems like the existence of dark matter. Here we will be concerned with sterile neutrinos.

Second, the LHC has found the Higgs-boson of the standard model and its mass is now known to be about 126 GeV. As a consequence predictions can be made within the standard model at the quantum level with an unprecedented precision. Therefore we can now make tests on the model that were not possible before. In the past most tests assumed lepton universality implicitly, in order to be able to use the precision data from LEP to put limits on the Higgs-boson mass. Now that the Higgs-boson mass is known, this is not sufficient anymore. One needs to combine the LEP data with low energy measurements, that have also been improved. In the presence of sterile neutrinos, the PMNS (Pontecorvo-Maki-Nakagawa-Sakata) matrix, that describes the mixing between the active neutrinos, coupled to the weak interactions, is only part of the general neutrino mixing matrix. The full neutrino mixing matrix is of course unitary, but the PMNS matrix is only a 3x3 submatrix of the full matrix and therefore not unitary. The deviations from unitarity can be described by the parameters $\epsilon_e, \epsilon_\mu, \epsilon_\tau$, that describe the amount of mixing of the e, μ, τ neutrinos to the sterile neutrino sector. As a consequence the couplings of the fermions to the weak vector bosons are reduced by the ϵ parameters.

We performed a χ^2 fit to the most precise data[3], consisting of τ -decays, π -decays, test of the unitarity of the Cabibbo-Kobayashi-Maskawa matrix, LEP-data and the W-boson mass. The combination of all data is sensitive to values of $\mathcal{O}(10^{-3})$ of the ϵ -parameters. We found a very good fit to the data with the following characteristics. We found a 3-sigma deviation from zero $\epsilon_e = 2.5 \pm 0.8 \cdot 10^{-3}$, with ϵ_μ small and ϵ_τ badly constrained. In order to get an acceptable fit to the data, the measurement of the forward-backward asymmetry in the bottom quarks at LEP, which has always been problematic, had to be left out. To come

to a firm conclusion of course more experimental input is required. From the experimental point of view the analysis is interesting, because results from practically every high-energy accelerator contribute. Improvements on measurements of the W-boson mass, $\alpha(m_Z)$, τ -decays and the weak mixing angle will all contribute and can lead to an overall 5-sigma effect. Such experiments are ongoing worldwide. The main point of this contribution is to point out, that these experiments, though not designed for this purpose, can contribute in a fundamental way to elucidate the question of the nature of dark matter in the universe. Incidentally this proves, that the traditional differentiation between so-called discovery machines and so-called precision machines is spurious. The motto here is :

$$\text{PRECISION} = \text{DISCOVERY} !.$$

This work was supported by the Bundesministerium für Bildung und Forschung within the Förderschwerpunkt *Elementary Particle Physics*.

References

- [1] J. J. van der Bij, Phys. Rev. D **76** (2007) 121702, [arXiv:0708.4179 [hep-th]].
- [2] J. J. van der Bij, Gen. Rel. and Grav. **43** (2011) 2499, DOI 10.1007/s10714-010-1053-x, [arXiv:1001.3236 [hep-ph]].
- [3] L. Basso, O. Fischer and J. J. van der Bij, Europhys. Lett. **105** (2014) 11001 [arXiv:1310.2057 [hep-ph]] and references therein.

2.2 MC Generators for $e^+e^- \rightarrow$ hadrons at Low Energy

S. Eidelman, G. Fedotov, V. Ivanov, A. Korobov

Budker Institute of Nuclear Physics SB RAS and
Novosibirsk State University, Novosibirsk, Russia

Two detectors, CMD-3 and SND, are now operated at the VEPP-2000 e^+e^- collider with a goal of high-precision measurements of various multihadronic cross sections [1]. Here we briefly describe several Monte Carlo (MC) generators created for these experiments.

One of them considers the final state $K\bar{K}\pi$ with all three charge combinations possible ($K^+K^-\pi^0$, $K^0\bar{K}^0\pi^0$, $K^+\bar{K}^0\pi^-$). For each of them there are a few interfering intermediate mechanisms. For example, for $K^+K^-\pi^0$ and $K^0\bar{K}^0\pi^0$ there are at least three: $\phi\pi^0$, $K^*(892)\bar{K}$ and direct three-body $K\bar{K}\pi$ (production of higher mass K^* states is also possible). It has been shown that interference effects can be rather large and should be carefully taken into account in the analysis of experiments on $e^+e^- \rightarrow K\bar{K}\pi$ [2] and $\tau^- \rightarrow (K\bar{K}\pi)^-\nu_\tau$ [3, 4].

For two-body leptonic and hadronic final states ($e^+e^- \rightarrow e^+e^-$, $\mu^+\mu^-$, $\pi^+\pi^-$, K^+K^-) [5] as well as for the two-photon annihilation ($e^+e^- \rightarrow \gamma\gamma$) [6] there is an MC generator MCGPJ providing a 0.2% accuracy. This rather aggressive high accuracy is based on the accuracy claimed by the authors of the corresponding theoretical evaluations and should be thoroughly checked by confronting experimental $\mu^+\mu^-\gamma$ and $\pi^+\pi^-\gamma$ events with a real photon to results of MC simulation using the generator.

We have also continued working on a generic MC generator of $e^+e^- \rightarrow$ hadrons below 2 GeV [7]. New processes were added, matrix elements for more processes included. In view of the importance of the energy range from 2 and 3 GeV for various applications like muon anomalous magnetic moment, running fine structure constant etc. it is worth discussing whether or not it is possible to extend the approach of this generator to the higher energy range. This task is not easy because of a much higher number of final states accessible, but not impossible after ISR measurements at Belle and BaBar as well as BESIII.

This work is supported by the Ministry of Education and Science of the Russian Federation, the RFBR grants 12-02-01032, 13-02-00215 and the DFG grant HA 1457/9-1.

References

- [1] F. Ignatov, PoS EPS-HEP2013, 350 (2014).
- [2] B. Aubert et al., Phys. Rev. D **77**, 092002 (2008).
- [3] K. Abe et al., Phys. Lett. B **643**, 5 (2006).
- [4] B. Aubert et al., Phys. Rev. Lett. **100**, 011801 (2008).
- [5] A.B. Arbuzov et al., Eur. Phys. C **46**, 689 (2006).

- [6] S.I. Eidelman et al., Eur. Phys. C **71**, 1597 (2011).
- [7] H. Czyż et al., arXiv:1312.0454.

2.3 Towards a Precision Measurement of the Muon Pair Asymmetry in e^+e^- Annihilation at Belle and Belle II

T. Ferber

Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany

The process $e^+e^- \rightarrow \mu^+\mu^-$ is among the simplest reactions of the Standard Model (SM) where both quantum electrodynamics (QED) and electroweak (EW) predictions can be tested. The distribution of the polar angle θ^* of the outgoing leptons in the center of mass system, defined as the angle between the e^+ and the μ^\pm , is expected to be asymmetric in the SM at Born level, caused by the interference of γ and Z exchange even at energies well below the Z pole, whereas lowest-order QED predicts a symmetric angular distribution. The forward-backward asymmetry is defined as

$$\mathcal{A}_{FB}^\pm \equiv \frac{N^\pm(\cos(\theta^*) \geq 0) - N^\pm(\cos(\theta^*) < 0)}{N^\pm(\cos(\theta^*) \geq 0) + N^\pm(\cos(\theta^*) < 0)}, \quad (2.3.1)$$

where $N^\pm(\cos(\theta^*))$ is the number of μ^\pm detected under the angle $\cos(\theta^*)$. At lowest order and neglecting initial and final state masses, the forward-backward asymmetry for $s \ll M_Z^2$ can be approximated as

$$\mathcal{A}_{FB}^+(s) = -\mathcal{A}_{FB}^-(s) = \mathcal{A}_{FB}(s) \approx \frac{3G_F}{4\sqrt{2}\pi\alpha} \frac{sM_Z^2}{s - M_Z^2} g_A^e g_A^\mu, \quad (2.3.2)$$

where s is the squared center of mass energy, G_F is the Fermi constant, α is the QED coupling constant, M_Z is the Z boson mass and g_A^e and g_A^μ are the axial couplings of the electron and the muon. Previous measurements of \mathcal{A}_{FB} are shown in Fig. 2.3.1. The forward-backward asymmetry \mathcal{A}_{FB} is proportional to the ρ parameter via $g_A^f = \sqrt{\rho_f} T_3^f$, where $T_3^f = 1/2$ is the third component of the weak isospin and $f = e, \mu$. In the SM containing only Higgs doublets the ρ parameter at lowest order is equal to unity [1]. Deviation of the extracted ρ parameter and its SM expectation after applying flavour-universal (u) and flavour-specific (f) virtual corrections

$$\rho_f = 1 + \Delta\rho_u + \Delta\rho_f + \Delta\rho_{\text{new}} \quad (2.3.3)$$

can, e.g., be related to isospin violating New Physics through the oblique parameter T [2], where the contribution to the low energy ($s \ll M_Z^2$) ρ parameter is approximately given by $\Delta\rho_{\text{new}} \approx \alpha_Z T$ [3, 4] where $\alpha_Z \approx 1/128.945$ is the electromagnetic coupling at the Z pole. This measurement is unique in the sense that it probes axial-axial operators and allows an extraction of the oblique parameter T that is independent of the oblique parameter S .

Using the existing unskimmed part of the Belle data with about 8×10^8 muon pairs (corresponding to about 0.7 ab^{-1}), a precision measurement of $\mathcal{A}_{FB}((10.58 \text{ GeV})^2)$ with an expected statistical uncertainty of $\sigma(\mathcal{A}_{FB}) \approx 10^{-4}$ (i.e. $\sigma(\mathcal{A}_{FB})/\mathcal{A}_{FB} \approx 1\%$) is possible, where the lowest-order SM prediction is $\mathcal{A}_{FB}^0((10.58 \text{ GeV})^2) \approx -0.77\%$. The Belle II experiment expects to collect about 50 ab^{-1} until 2023, thus reducing the expected statistical

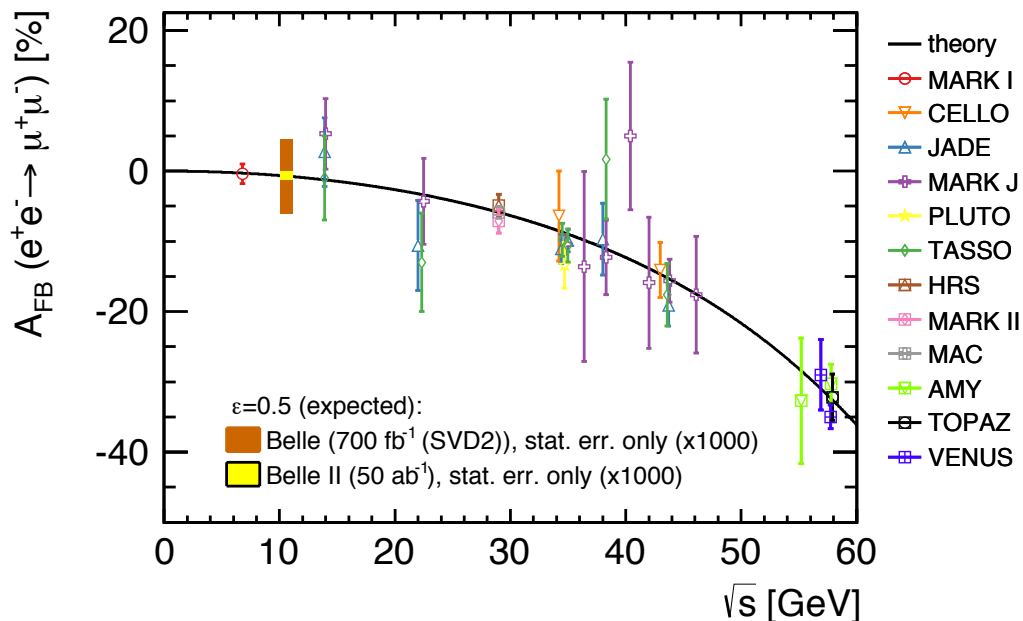


Figure 2.3.1: Measurements of $\mathcal{A}_{FB}(e^+e^- \rightarrow \mu^+\mu^-)$ at different energies \sqrt{s} corrected for QED effects by the respective authors (see [5] and references therein), theoretical SM prediction at lowest order and the expected Belle and Belle II statistical uncertainties (scaled up by a factor of 1000) at $\sqrt{s} = 10.58$ GeV.

uncertainty ($\sigma(\mathcal{A}_{FB}) \propto 1/\sqrt{N}$) to $\sigma(\mathcal{A}_{FB}) \approx 10^{-5}$.

Apart from detector and background induced asymmetries and higher order weak virtual corrections, QED asymmetries of $\mathcal{O}(10^{-2})$ arise, mainly from interference (IFI) of initial and final state radiation and box diagrams. These asymmetries have to be corrected using Monte Carlo (MC) simulations. Ensuring both the theoretical uncertainty of \mathcal{A}_{FB} and the implementation in the MC generators being understood at the level of $\sigma_{QED+EW}(\mathcal{A}_{FB}) \lesssim 10^{-5}$ make a detailed comparison of available (semi)analytical calculations and MC event generators mandatory. Such comparisons have been performed at energies around and above M_Z for LEP1 and LEP2 energies before, but not at energies $s \ll M_Z^2$.

Two questions will be addressed using two independent (semi)analytical packages, one including the final state masses exactly (topfit) [6, 7] and ZFITTER [8, 9], for idealized observables: Firstly, the final state muon mass beyond kinematic effects and secondly beyond one-loop electroweak corrections. If the effect of a non-zero final state muon mass is negligible for the required precision, ZFITTER can be used to study systematic effects after switching off beyond one-loop weak corrections in DIZET that includes approximations valid at the Z pole only and hence must be used carefully at $\sqrt{s} = 10.58$ GeV.

The ultimate step is to compare the two MC generators that are expected to principally provide the required precision needed to correct for QED effects and detector acceptance for

a realistic event selection: KKMC 4.19¹ [10] and PHOKHARA 9.0 [11]. For the QED parts relevant to the forward–backward asymmetry measurement, both generators differ mainly in the treatment of IFI, which is included in PHOKHARA 9.0 up to complete NLO and in KKMC up to leading order plus coherent exclusive exponentiation [12]. PHOKHARA lacks the inclusion of Z exchange and γZ interference, whose implementation should be straightforward, though. Since for a MC statistical uncertainty below $\sigma(\mathcal{A}_{FB})_{MC\,stat.} \approx 10^{-5}$ one needs to generate $\mathcal{O}(10^{10})$ events, this is one of the reasons why it would be preferable to use tools like ZFITTER to evaluate systematics effects whenever applicable.

The measurement of \mathcal{A}_{FB} with an absolute statistical uncertainty of $\sigma(\mathcal{A}_{FB}) \approx 10^{-5}$ at Belle II would allow precision tests of the SM, e.g. via the oblique parameter T , using the well defined forward–backward asymmetry below the Z pole if systematic uncertainties can be kept below 10^{-5} . The required precision tag for QED corrections clearly is at the limit of currently available generators and needs to be understood. In addition, the planned work outlined above can serve as a benchmark for further generator studies for low energy e^+e^- colliders within the Radio MonteCarLow working group.

References

- [1] D. Bardin and G. Passarino, “The Standard Model in the Making: Precision Study of the Electroweak Interactions”, Clarendon, Oxford (UK), 1999.
- [2] M. E. Peskin and T. Takeuchi, Phys. Rev. D **46** (1992) 381.
- [3] J. Erler and S. Su, Prog. Part. Nucl. Phys. **71** (2013) 119 [arXiv:1303.5522 [hep-ph]].
- [4] J. Erler, Talk at the 17th Open Meeting of the Belle II Collaboration (2014).
- [5] M. Miura *et al.*, Phys. Rev. D **57** (1998) 5345.
- [6] J. Fleischer *et al.*, Eur. Phys. J. C **31** (2003) 37 [hep-ph/0302259].
- [7] T. Hahn *et al.*, in Proc. of 4th ECFA/DESY LCWS, DESY 04-123G [hep-ph/0307132].
- [8] D. Y. Bardin *et al.*, Comput. Phys. Commun. **133** (2001) 229 [hep-ph/9908433].
- [9] A. B. Arbuzov *et al.*, Comput. Phys. Commun. **174** (2006) 728 [hep-ph/0507146].
- [10] S. Jadach *et al.*, Comput. Phys. Commun. **130** (2000) 260 [hep-ph/9912214].
- [11] F. Campanario *et al.*, JHEP **1402** (2014) 114 [arXiv:1312.3610 [hep-ph]].
- [12] S. Jadach *et al.*, Phys. Rev. D **63** (2001) 113009 [hep-ph/0006359].

¹Since KKMC uses the same DIZET library as ZFITTER, the same arguments apply concerning higher order weak corrections for $\sqrt{s} = 10.58$ GeV.

2.4 Direct production of χ_{c1} — a 1^{++} charmonium at e^+e^- machine

Zhiqing Liu

Institute of Nuclear Physics, Johannes Gutenberg-University Mainz, Germany

Conventionally, an e^+e^- annihilation machine only produce resonances with quantum numbers $J^{PC} = 1^{--}$. This fact has been proved to be true since the discovery of the famous charmonium state — J/ψ [1]. Now, several decades after, with the improving luminosity of e^+e^- facilities, we are proposing to search for the direct production of a 1^{++} charmonium state — χ_{c1} , which sound impossible in e^+e^- annihilation, but indeed can be accessible via two-photon exchange process. We are aiming to give a Γ_{ee} measurement for the χ_{c1} resonance, which of course reflect the internal structure of this charmonium. Once the experimental approach has been established, we can extend our study to another charmoniumlike state — $X(3872)$ [2]. The $X(3872)$ is a well-known charmoniumlike state with same quantum number as χ_{c1} , however with an unknown nature. There are wide discussions whether this state is a hadron molecule [3] or tetraquark [4]. Our study of $X(3872)$ provides an unique way to probe its internal structure, and finally will help reveal its true nature.

The BESIII experiment [5] located in Beijing is an advanced modern e^+e^- machine. The machine runs from e^+e^- central-of-mass (cm) energy 2.0 GeV to 4.6 GeV, which covers the full energy range of charmonium states. The designed luminosity is $1.0 \times 10^{33} \text{cm}^{-2}\text{s}^{-1}$, which delivers high quality data roughly with average 15 pb^{-1} per day. Our strategy is like this, the χ_{c1} resonance is produced directly from e^+e^- two-photon exchange process at peak, and subsequently decay into $\gamma J/\psi \rightarrow \gamma \mu^+ \mu^-$. The dominant backgrounds come from $\gamma_{ISR} J/\psi \rightarrow \gamma_{ISR} \mu^+ \mu^-$ and $\gamma_{ISR} \mu^+ \mu^-$ events, which is estimated to be around 19 pb by MC simulation precisely [6] and also confirmed by existing data sets at BESIII. The Γ_{ee} value of χ_{c1} resonance is estimated by VMD model to be 0.46 eV [7]. Under this assumption, the bare signal cross section is estimated to be 637 pb. Considering initial-state-radiation (ISR) effect and beam energy spread [8], the real production cross section reduced to 115 pb. Taking in the branching ratios and acceptance effect, the final effective cross section is around 1.57 pb. With the signal to noise ratio $1.57/19=8.3\%$, we expect to observe an evidence (3σ significance) with 75 pb^{-1} data, and a signal (5σ significance) with 208 pb^{-1} data. Thanks to the good performance of BESIII, we are able to achieve χ_{c1} evidence with 5 days running, and observation with 2 weeks running.

References

- [1] J. J. Aubert *et al.*, Phys. Rev. Lett. **33**, 1404 (1974); J. E. Augustin *et al.*, Phys. Rev. Lett. **33**, 1406 (1974).
- [2] For a recent review, see N. Brambilla *et al.*, Eur. Phys. J. C **71**, 1534 (2011).
- [3] E. S. Swanson, Phys. Lett. B **598** (2004) 197.

- [4] L. Maiani, F. Piccinini, A. D. Polosa, and V. Riquer, Phys. Rev. D **71**, 014028 (2005).
- [5] M. Ablikim *et al.* (BESIII Collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A **614**, 345 (2010).
- [6] H. Czyż, J. H. Kühn and A. Wapienik, Phys. Rev. D **77** 114005 (2008).
- [7] J. H. Kühn, J. Kaplan and E. G. O. Safiani, Nucl. Phys. B **157** (1979) 125.
- [8] E. V. Abakumova, M. N. Achasov, V. E. Blinov, X. Cai, H. Y. Dong, C. D. Fu, F. A. Harris and V. V. Kaminsky *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A **659**, 21 (2011).

2.5 Monte Carlo Generators for the study of the process $e^+e^- \rightarrow 2(\pi^+\pi^-\pi^0)$ with the CMD-3 detector

P. A. Lukin

Budker Institute of Nuclear Physics and Novosibirsk State University, Novosibirsk, Russia

The CMD-3 detector [1] at VEPP-2000 e^+e^- collider [2] takes data in center-of-mass energy range $E_{cm} = 0.32 - 2.0$ GeV. During experimental seasons of 2011 – 2013 the luminosity integral of about 60 pb^{-1} has been collected. The analysis of the data is in progress and has been reported elsewhere (see, for example, [3]). The study of the process $e^+e^- \rightarrow 3(\pi^+\pi^-)$ was finished and published [4]. Now the 6π process in the channel $e^+e^- \rightarrow 2(\pi^+\pi^-\pi^0)$ is under study.

In measurement of the cross section of any process it is important to describe correctly angular correlations between particles in final state in order to correctly calculate registration efficiency of the process. So, it was our main goal in development of the Monte Carlo generators, although, studying of intermediate states is interesting itself. We started to investigate distribution of events over invariant mass of three pions with zero charged. The corresponding plot is shown in Fig. 2.5.1. Clear signals from $\omega(782)$ and $\eta(545)$ mesons are seen. So, we need to take into account following intermediate contributions of $2(\pi^+\pi^-\pi^0)$

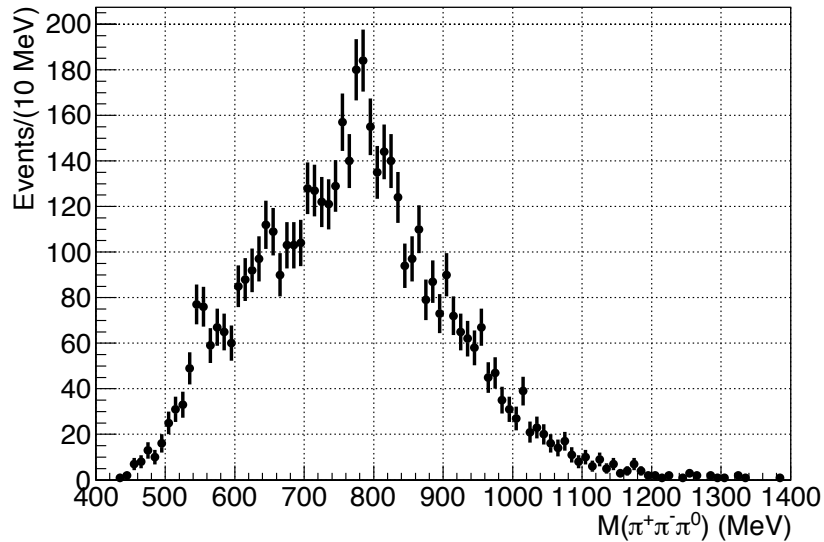


Figure 2.5.1: Distribution of $2(\pi^+\pi^-\pi^0)$ events over $\pi^+\pi^-\pi^0$ invariant mass at $E_{cm} = 1.72$ GeV.

final state production:

$$\begin{aligned} e^+e^- &\rightarrow \omega(782)\pi^+\pi^-\pi^0 \rightarrow 2(\pi^+\pi^-\pi^0) \\ e^+e^- &\rightarrow \omega(782)\eta(545) \rightarrow 2(\pi^+\pi^-\pi^0). \end{aligned}$$

As it was obtained from BaBar studying [5] and confirmed by the CMD-3 experiment [4] there is only one $\rho(770)$ -meson production in 6π final state. Therefore, in present work we also used Monte-Carlo generator $e^+e^- \rightarrow \rho(770)(4\pi)_{S-wave}$. Using these three processes we tried to describe mass and angular distributions of the $2(\pi^+\pi^-\pi^0)$ final state.

In Figure 2.5.2(left) one can see the distribution of experimental $2(\pi^+\pi^-\pi^0)$ events at $E_{cm} = 1.72$ GeV over invariant mass of $\pi^+\pi^-\pi^0$ (points with errors), fitted with the sum of simulated distributions of the processes $\omega(782)\pi^+\pi^-\pi^0$, $\omega(782)\eta(545)$ and $\rho(770)(4\pi)_{S-wave}$. Fit result is shown as a histogram on the Fig. 2.5.2(left). The following fractions of the different contributions have been obtained:

$$\begin{aligned} f_{\omega(782)3\pi} &\sim 60\% \\ f_{\rho(770)(4\pi)_{S-wave}} &\sim 30\% \\ f_{\omega(782)\eta(545)} &\sim 10\% \end{aligned}$$

The obtained values we applied to describe distribution of the experimental data events over invariant mass of $\pi^\pm\pi^0$ with the sum of three simulated process. The result is presented in Figure 2.5.2(right). The fractions of different contributions, onbtained from the fit of

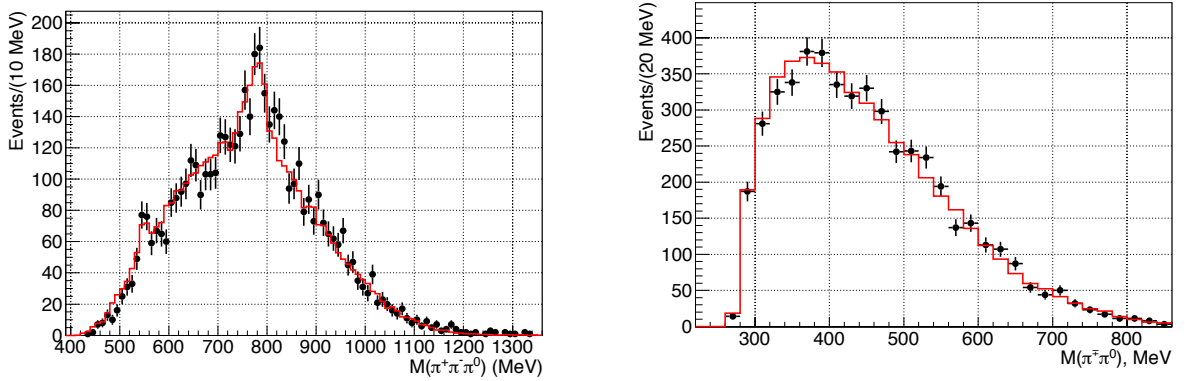


Figure 2.5.2: On the left plot: Distribution of experimental data events over invariant mass of $\pi^+\pi^-\pi^0$ (points with errors) fitted with the sum of three contributions (histogram). On the right plot: Distribution of experimental data events over invariant mass of $\pi^\pm\pi^0$ (points with errors), described by the sum of three contributions (histogram). See details in the fit.

the distribution in Figure 2.5.2(left) were also used to describe angular correlations between particles in a $2(\pi^+\pi^-\pi^0)$ final state. In Figure 2.5.3 is shown cosines of angles between (from left to right and from top to bottom) $\pi^+\pi^-$, $\pi^+\pi^+$, $\pi^-\pi^-$, $\pi^0\pi^0$, $\pi^0\pi^+$ and $\pi^0\pi^-$ for experimental data (points with errors) and for simulation (histogram) of three contributions — $\omega(782)3\pi$, $\omega(782)\eta(545)$ and $\rho(770)(4\pi)_{S-wave}$ with relative fractions, determined from the

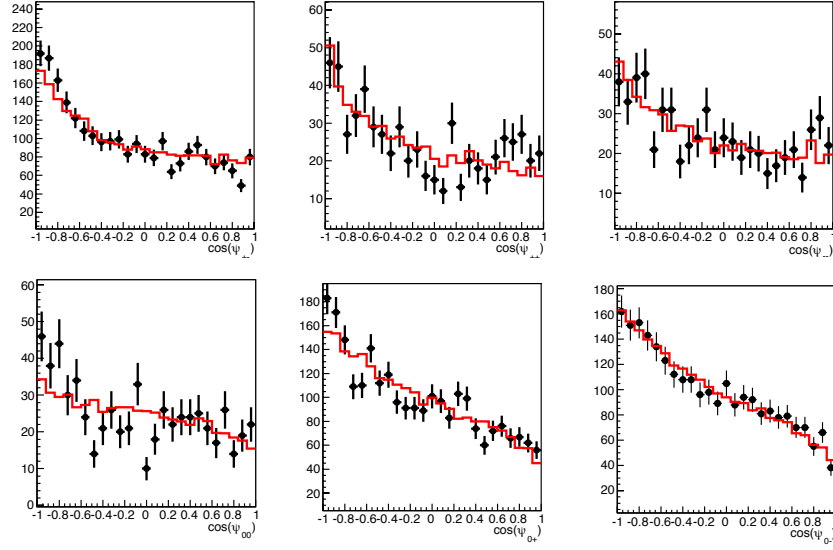


Figure 2.5.3: Cosines of angles between (from left to right and from top to bottom) $\pi^+\pi^-$, $\pi^+\pi^+$, $\pi^-\pi^-$, $\pi^0\pi^0$, $\pi^0\pi^+$ and $\pi^0\pi^-$ for experimental data (points with errors) and for simulation (histogram) of three contributions — $\omega(782)3\pi$, $\omega(782)\eta(545)$ and $\rho(770)(4\pi)_{S-wave}$.

fit of distribution in Figure 2.5.2(left). Good agreement between experiment and simulation can be seen at all plots in the Figure.

As result of the work presented here the mass and angular distributions of the $2(\pi^+\pi^-\pi^0)$ events were described by the sum of three contributions $\rho(770)(4\pi)_{S-wave}$, $\omega(782)3\pi$ and $\omega(782)\eta(545)$ in center of mass energy range below 1.72 GeV. For energy above 1.72 new intermediate states should be investigated.

Author would like to thank organizers of XV RadioMonteCarlow meeting in April 2014 in Mainz (Germany) for support. This work is performed partly in the frame of program, described in [6].

References

- [1] B.I. Khazin. Nucl.Phys.Proc.Suppl.,181, (2008), 376.
- [2] V.V. Danilov *et al.* Proceedings EPAC96, Barcelona,(1996), 1593.
I.A.Koop. Nucl.Phys.Proc.Suppl.,181, (2008), 371
- [3] F.V. Ignatov *et al.* PoS EPS-HEP2013, (2014), 350.
- [4] R.R. Akhmetshin *et al.* Phys.Lett. B723 (2013) 82.
- [5] B. Aubert *et al.*, Phys.Rev. D73 (2006) 052003
- [6] S. Actis *et al.*, Eur.Phys.J. C66 (2010) 585.

2.6 Update on the combined estimate of the KLOE ISR measurements

S. E. Müller

Institute of Radiation Physics, Helmholtz-Zentrum Dresden-Rossendorf, Germany

The KLOE experiment at the Frascati ϕ -factory DAΦNE has published 4 data sets for the cross section of the process $e^+e^- \rightarrow \pi^+\pi^-$ below 1 GeV [1, 2, 3, 4]. As already described at the last meeting, work is in progress to combine the 3 data sets KLOE08 [2], KLOE10 [3] and KLOE12 [4]¹ using the method of the *best linear unbiased estimator* (BLUE) [5]. In [6], the method is extended to the combination of correlated measurements of several different observables, and an analytic solution is given to find the best estimates using the covariance matrix of the measurements. In our case, this involves the construction of the covariance matrix for the 195 data points of the three KLOE measurements [7, 8, 9]. Since the presence of normalization errors in the (195×195) covariance matrix \mathcal{M}_{ij} leads to a bias in the evaluation of the best estimates [10], the BLUE values are constructed using only the covariance matrix with statistical uncertainties. The covariance matrix that contains the normalization errors is then propagated properly a posteriori to the (85×85) covariance matrix of the best estimates.

As described in [6], the BLUE method is equivalent to the problem of finding the estimates \hat{x}_α minimizing the sum

$$S = \sum_{\alpha=1}^N \sum_{\beta=1}^N \sum_{i=1}^n \sum_{j=1}^n [\mathcal{U}_{i\alpha}(y_i - \hat{x}_\alpha)] \mathcal{M}_{ij}^{-1} [\mathcal{U}_{j\beta}(y_j - \hat{x}_\beta)], \quad (2.6.1)$$

in which the matrix $\mathcal{U}_{i\alpha}$ links the 195 data values from the KLOE publications y_i to the 85 BLUE values \hat{x}_α (see [6, 7]). \mathcal{M}_{ij} is the (statistical) covariance matrix described above. Assuming that errors are Gaussian, the minimum of S should be distributed as a χ^2 with $(n - N) = 195 - 85 = 110$ degrees of freedom. This can be used to estimate how consistent the individual measurements are with their combined estimates. In the present evaluation of the BLUE values, a value of $\chi^2_{\text{tot}}/\text{ndf} = 183/110$ is found, with a χ^2 -probability of $P \simeq 1.5 \times 10^{-5}$. This low value of probability can be justified by the fact that the method used to obtain the combined estimates only uses the statistical covariance matrix. Data points with large normalization uncertainties will therefore spoil the sum S in eq. 2.6.1, therefore limiting the use of the S -value in as a consistency check for the BLUE method used to obtain the combined estimates. Keeping only the terms with $\alpha = \beta$, one can estimate the individual contributions S_α to eq. 2.6.1 for each value of the \hat{x}_α :

$$S_\alpha = \sum_{i=1}^n \sum_{j=1}^n [\mathcal{U}_{i\alpha}(y_i - \hat{x}_\alpha)] \mathcal{M}_{ij}^{-1} [\mathcal{U}_{j\alpha}(y_j - \hat{x}_\alpha)] \quad (2.6.2)$$

¹The KLOE05 [1] data set is superseded by the more precise KLOE08 [2] analysis

Preliminary studies show that large values for S_α are found at the $\rho - \omega$ interference region (where large uncertainties due to the procedure used to unfold the data from detector resolution are present) and around the value of 0.5 GeV^2 (where two points of the dominant KLOE08 data set pull the combined estimates away from the corresponding values of the KLOE10 and KLOE12 data).

While the statistical contributions to the combined covariance matrix are under control, to conclude the work, a better understanding on the correlation between the systematic uncertainties of the KLOE08 and the KLOE12 analysis is needed. Currently, a full correlation between the two is assumed. It remains to be checked whether this assumption is valid.

References

- [1] A. Aloisio *et al.* [KLOE Collaboration], Phys. Lett. B **606**, 12 (2005) [hep-ex/0407048].
- [2] F. Ambrosino *et al.* [KLOE Collaboration], Phys. Lett. B **670**, 285 (2009) [arXiv:0809.3950 [hep-ex]].
- [3] F. Ambrosino *et al.* [KLOE Collaboration], Phys. Lett. B **700**, 102 (2011) [arXiv:1006.5313 [hep-ex]].
- [4] D. Babusci *et al.* [KLOE Collaboration], Phys. Lett. B **720**, 336 (2013) [arXiv:1212.4524 [hep-ex]].
- [5] L. Lyons, D. Gibaut and P. Clifford, Nucl. Instrum. Meth. A **270** (1988) 110.
- [6] A. Valassi, Nucl. Instrum. Meth. A **500** (2003) 391.
- [7] H. Czyż, S. Eidelman, G. V. Fedotov, A. Korobov, S. E. Müller, A. Nyffeler, P. Roig and O. Shekhovtsova *et al.*, arXiv:1312.0454 [hep-ph].
- [8] P. Masjuan, G. Venanzoni, H. Czyż, A. Denig, M. Vanderhaeghen *et al.*, arXiv:1306.2045 [hep-ph].
- [9] Data tables and covariance matrices:
<http://www.lnf.infn.it/kloe/ppg>.
- [10] G. D’Agostini, Nucl. Instrum. Meth. A **346**, 306 (1994).

2.7 Gradient method with re-weighted events and its implementation for TAUOLA to fit the three pion mode

J. Zaremba

Institute of Nuclear Physics, PAN, Kraków, Poland

Recently, models based on the Resonance Chiral Lagrangian Theory [1] have been included into the Monte Carlo (MC) generator TAUOLA for simulating hadronic τ decays. Models such as these must be tuned to the experimental data. For that purpose, a gradient method which uses MC re-weighting to morph the MC template used to tune the models has been adopted as one of the alternatives [2].

This method is motivated by its wide range of applications. For example, it can be used for data which has not been unfolded to account for the detector resolution, efficiency and experimental cuts. This is particularly useful for both multidimensional distributions and when fitting multiple channels at once.

In this approach, Monte Carlo sample is generated once and then re-used for fitting. When a set of the model parameters is changed, each event is given a weight which corresponds to the ratio of the matrix element calculated with the new set of parameters to the matrix element calculated at the time of generation. By using this re-weighting technique, one obtains both a numerically stable template which is suitable for fitting and reduces the computation time for generating the sample.

Since the model used in TAUOLA contains up to 15 parameters, taking into account time-consumption, scanning parameter-space randomly is not a reasonable option. In a first approximation, one can assume linear dependence on parameters. The assumption can always be made even if model is complicated. Through re-weighting we can morph our MC sample to any point of parameter space. Moreover, this technique allows us to construct any distribution available in the experiment. Using the Taylor expansion, a linear model can be constructed for a given point in the parameter space for each event. Since this simplified model holds for a linear combination of events, the simplified model can be constructed for each bin of the histograms. This enables standard tools like Minuit2 to be used to fit the simplified model to the experimental data. Then the procedure is repeated using this new set of parameters as starting point. As one can expect such a method is bound to circle around minima and requires further improvement.

As the most problematic issue is choosing the step size for the parameters such that one does not skip over the minima. In order to achieve this, one must incorporate information from the second derivatives. To address this problem, one must estimate the region of validity for the linear assumption of the simplified model. As a first estimate, this can be done by demanding that the ratio of the first to second order term in the Taylor expansion is much larger than a predefined value. The cross terms for the second order derivatives were neglected to reduce the computational time. This strategy provided a reasonable preliminary result in 10-20 iterations, a couple of days. However, full convergence can not be expected in this timescale. Due to the availability of the unfolded data from the experiments, further

improvements to this method, such as an adaptive step-size, were not implemented.

In parallel with development of the discussed method, a semi-analytical fit was performed [3] allowing cross-check with the approach in [4]. Even though full convergence, error evaluation, etc. is not yet possible for the Gradient method, results from both methods are very similar and they lead to same conclusions about the model used in **TAUOLA**. Agreement represents technical cross-check of the methods. These studies will be continued to evaluate method performance. It will be important for future studies, when semi-analytical distributions and unfolded spectra of experimental data will not be available.

The author wishes to thank the organizers of the fifteenth meeting of the Radio Monte Carlo Working Group for support. Partially this project is financed from funds of Foundation of Polish Science grant POMOST/2013-7/12. POMOST Programme is co-financed from European Union, Regional Development Fund. This project is financed in part from funds of Polish National Science Centre under decisions DEC-2011/03/B/ST2/00107. Part of the computations were supported in part by PL-Grid Infrastructure (<http://plgrid.pl/>) and were performed on ACK Cyfronet computing cluster (<http://www.cyfronet.krakow.pl/>).

References

- [1] O. Shekhovtsova, T. Przedzinski, P. Roig, Z. Was, Phys.Rev. D86 (2012) 113008, [arXiv:1203.3955 [hep-ph]]
- [2] J. Zaremba Master Degree thesis, <http://annapurna.ifj.edu.pl/~jzaremba/>.
- [3] I. M. Nugent, T. Przedzinski, P. Roig, O. Shekhovtsova, Z. Was, Phys. Rev. D 88, 093012 (2013) [arXiv:1310.1053v2 [hep-ph]]
- [4] I. M. Nugent, T. Przedzinski, P. Roig, O. Shekhovtsova, Z. Was, J. Zaremba, "Confronting theoretical predictions with experimental data; fitting strategy for multi-dimensional distributions", IFJPAN-IV-2014-5

3 List of participants

- J. J. van der Bij, Albert-Ludwigs Universität Freiburg, `vdbij@physik.uni-freiburg.de`
- S. S. Caiazza, Johannes Gutenberg-Universität Mainz, `caiazza@kph.uni-mainz.de`
- C. M. Carloni-Calame, Pavia University `carlo.carloni.calame@pv.infn.it`
- H. Czyż, University of Silesia, `henryk.czyz@us.edu.pl`
- A. Dbeyssi, Johannes Gutenberg-Universität Mainz, `dbeyssi@kph.uni-mainz.de`
- A. Denig, Johannes Gutenberg-Universität Mainz, `denig@kph.uni-mainz.de`
- S. Eidelman, Novosibirsk State University, `eidelman@mail.cern.ch`
- T. Ferber, DESY Hamburg, `torben.ferber@desy.de`
- Y. Guo, Johannes Gutenberg-Universität Mainz, `guo@kph.uni-mainz.de`
- A. Hafner, Johannes Gutenberg-Universität Mainz, `hafner@kph.uni-mainz.de`
- M. Hoferichter, Albert Einstein Center for Fundamental Physics, Universität Bern, `hoferichter@itp.unibe.ch`
- H. Hu, IHEP Beijing, `huhm@ihep.ac.cn`
- G. Huang, University of Science and Technology of China, `hgs@ustc.edu.cn`
- F. Jegerlehner, Humboldt-Universität zu Berlin, `fjeger@physik.hu-berlin.de`
- B. Kloss, Johannes Gutenberg-Universität Mainz, `kloss@uni-mainz.de`
- W. Kluge, Institut für Experimentelle Kernphysik KIT, `wolfgang.kluge@partner.kit.edu`
- A. Kupsc, Uppsala University, `Andrzej.Kupsc@physics.uu.se`
- Z. Liu, Johannes Gutenberg-Universität Mainz, `liuz@uni-mainz.de`
- P. Lukin, Budker Institute of Nuclear Physics and Novosibirsk State University, `P.A.Lukin@inp.nsk.su`
- S. E. Müller, Helmholtz-Zentrum Dresden-Rossendorf, `stefan.mueller@hzdr.de`
- A. Nyffeler, `nyffeler@itp.unibe.ch`
- C. F. Redmer, Johannes Gutenberg-Universität Mainz, `redmer@kph.uni-mainz.de`
- M. Ripka, Johannes Gutenberg-Universität Mainz, `ripka@uni-mainz.de`
- B. Schwartz, Budker Institute of Nuclear Physics, `schwartz@inp.nsk.su`

- E. Solodov, Budker Institute of Nuclear Physics, `E.P.Solodov@inp.nsk.su`
- T. Teubner, University of Liverpool, `thomas.teubner@liverpool.ac.uk`
- M. Unverzagt, Johannes Gutenberg-Universität Mainz,
`unvemarc@kph.uni-mainz.de`
- G. Venanzoni, Laboratori Nazionali di Frascati dell'INFN,
`Graziano.Venanzoni@lnf.infn.it`
- Y. Wang, Johannes Gutenberg-Universität Mainz, `whyaqm@gmail.com`
- S. Wagner, Johannes Gutenberg-Universität Mainz, `wagners@kph.uni-mainz.de`
- J. Zaremba, Institute of Nuclear Physics, PAN, Kraków, Poland,
`jakub.zaremba@ifj.edu.pl`